J. Application of Thread-Forming Fasteners in Net-Shaped Holes

Principal Investigator: Dean M. Paxton
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352
(509) 375-2620; fax: (509) 375-2186; e-mail: dean.paxton@pnl.gov

Contract Manager: Mark T. Smith
Pacific Northwest National Laboratory
P.O. Box 999, Richland, WA 99352
(509) 375-4478; fax: (509) 375-4448; e-mail: mark.smith@pnl.gov

Technology Area Development Manager: Joseph Carpenter
(202) 586-1022; fax: (202) 586-1600; e-mail: joseph.carpenter@ee.doe.gov
Field Technical Manager: Philip S. Sklad
(865) 574-5069; fax: (865) 576-4963; e-mail: skladps@ornl.gov

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Objective

- To demonstrate concept feasibility of applying thread-forming fasteners (TFFs) into net-shaped hole features in light alloy die castings of aluminum and magnesium for automotive applications.

Accomplishments

- Completed at ELM International design and fabrication of a die casting tool as well as cast aluminum and magnesium nut and washer specimens for testing.
- Obtained from Ford Motor Company and DaimlerChrysler, final machining of nut and washer specimens. They also provided x-radiography of the final machined test specimens.
- Obtained from Bosch Rexroth, a Fastener Tightening and Control System (nut-runner) for driving fasteners into test specimens, which was integrated with the Labmaster Fastener Evaluation Test Cell in use at PNNL.
- Obtained from Textron Fastening Systems, several types of M6 Taptite TFFs for this project as well as standard machine fasteners for comparison.
- Conducted a parametric study at PNNL to evaluate the effects of hole size geometry, fastener coating, and thread engagement depth on clamp load of the joint.
- Performed metallographic examinations of TFFs in cast specimens with net-shaped holes were performed to characterize thread integrity relative to cast specimens with tapped holes and standard machine fasteners.
- Established a broad-based team of contributors for moving forward with the Technical Feasibility portion of this program, including the automotive OEMs, fastener suppliers, assembly equipment suppliers, and manufacturers of cast components.

Future Direction

- Understand and predict casting variation as it applies to the application of TFFs in aluminum castings.
- Optimize fastener design with appropriate coatings for as-cast aluminum and magnesium.
- Understand and control the consequences of in-service reusability and contamination.
- Apply specific assembly process control for component-specific applications.

Introduction

Progress has been made in applying TFFs into machined or stamped holes featured in automotive applications for general assembly. Use of these fasteners eliminated the tapping operation and thereby reduced costs, reduced investment, and improved warranty while delivering better joint properties within an assembly. However, little progress has been made in applying these fasteners into net-shaped holes in as-cast aluminum or magnesium components. Opportunities exist to further reduce costs by using TFFs with net-shaped holes in lightweight castings by eliminating the drilling operation and associated equipment investment without sacrificing joint performance. Potential applications for using TFFs in cast components are numerous and include powertrain (transmissions, engines, and rear axles); chassis (control arms, suspensions); and body structures that utilize large castings (inner doors, liftgates, under-hood attachments, and supports).

The concept feasibility portion of this program to investigate the use of TFFs in net-shaped holes was initiated in 2003. The objectives of the program were to (1) evaluate production die-casting dimensional capabilities to deliver net-sized and shaped holes, (2) demonstrate and characterize the application and use of TFFs for joining (in net-shaped holes), and (3) as required, identify the need for and application of new assembly strategies to support these new joint designs and processes.

Experimental Approach

To perform mechanical testing of TFFs into as-cast net-shaped holes, aluminum alloy A380 nut and washer plates were cast and machined into test specimens. The x-radiography inspections were performed on a sampling of castings prior to final machining to verify structural integrity of the casting. The nut specimens included blind holes with 0.5° and 1.0° draft angles. A photograph and cross-section schematic of these specimens are presented in Figures 1 and 2, respectively. In addition, as-cast nut test specimens were prepared without a preset hole to allow for drilling and/or tapping of holes for comparison testing. A limited number of magnesium alloy AZ91 nut and washer plates were cast and machined into specimens for preliminary testing. Textron Fasteners supplied 6-mm-diam (M6) Taptite fasteners with two coating

Figure 1. As-cast aluminum nut and washer specimens used for TFF torque-tension mechanical testing.

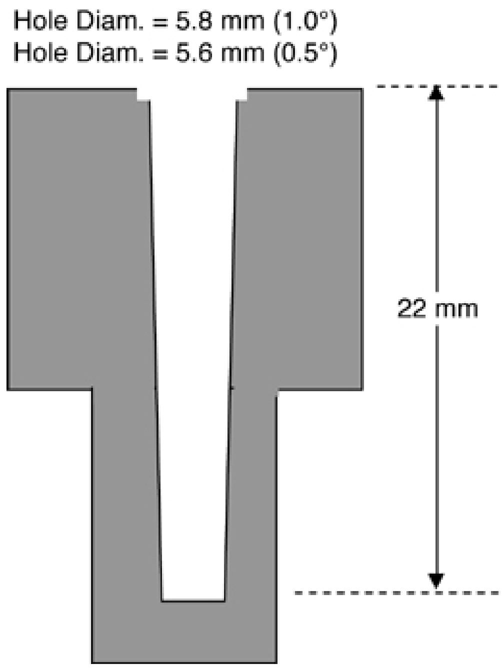

Figure 2. Cross section of nut specimen with blind hole at two draft angles (0.5° and 1.0°).

types: Magni 565, which is an organic coating, and an electroplated zinc coating referred to as S437. Textron also provided standard M6 machine screws coated with both the Magni 565 and S437 coatings for comparison testing. These fastener types were designed for use in aluminum.

The LabMaster Fastener Evaluation Test Cell was used to perform mechanical testing. This unit utilizes a slide-bearing mount for the fastener drive system in addition to mounting for the rotary torque-angle sensor and torque-tension research head. The fastener test system couples with a dc electric nut-runner tool and controller, a rotary torque-angle transducer, a combination thread torque and clamp force transducer, and a computer control system for accurate test reproduction as well as data logging and reporting. The test stand equipment and nut-runner provided by Bosch Rexroth are shown in Figure 3. Individual mounting plates (Figure 4) were machined to size to hold the nut and washer specimens on either side of the load cell. The nut-runner was programmed to drive the fasteners to failure at a rundown speed of 240 rpm. During testing, the Labmaster software recorded clamp load, input torque, and failure torque-vs-time and angular rotations of the fastener for each test.

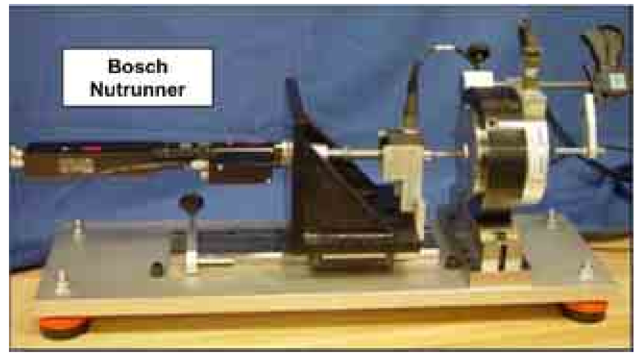

Figure 3. LabMaster Fastener Evaluation Test Cell from RS Technologies with integrated Bosch nutrunner.

Figure 4. Washer and nut plates used with fastener test stand.

To better understand the role of hole geometry and type (net-shape vs drilled) and to compare TFFs to standard machine screws, a parametric study was designed that also included fastener coating type and thread engagement depth. This study was focused on aluminum, although some limited testing was performed on the magnesium specimens. The variables and a symbol for each are listed in Table 1. With two coating types and four hole types, a total of eight combinations are established for each thread engagement depth (e.g., M0518 and S1015).

Table 1. Summary of test matrix parameters

Variable	Description	Symbol
Coating	Magni 565	M
	S437	S
Hole type	0.5° Draft angle	05
	1.0° Draft angle	10
	Drilled hole	DR
	Tapped hole	TP
Depth	18 mm	18
	15 mm	15

Experimental Results

The mechanical testing of installing fasteners into as-cast aluminum specimens was performed during August–September 2003. Initial testing at a thread engagement depth of 18 mm (equivalent to three times the diameter of the 6-mm fastener) showed that failure of the joint occurred by breaking of the fastener adjacent to the top surface of the nut specimen. This result indicates that the input torque applied during tightening of the joint exceeded the strength of the fastener, not the strength of the threads formed in the cast aluminum nut specimen. However, initial testing at a thread engagement of only 15 mm (two and one-half times the diameter of the 6-mm fastener) resulted in failure of the threads in the joint (stripping) rather than failure of the fastener. Failure in this mode does not yield usable data and is attributable to the hole size and draft angle, not specifically to the fastener. Thus, testing at the 15-mm engagement depth was discontinued, and results reported herein will be for the 18-mm depth. Different nut specimens and hole geometry would be required to evaluate two and one-half times thread engagement for specific applications.

Minimum failure torque (Nm) and maximum clamp load (kN) for each combination are shown in Figure 5 and summarized in Table 2. A total of 30 specimens were run at each combination to generate statistically significant data. In general, the minimum failure torque for joints with TFFs was consistent at ~25–26 Nm with the

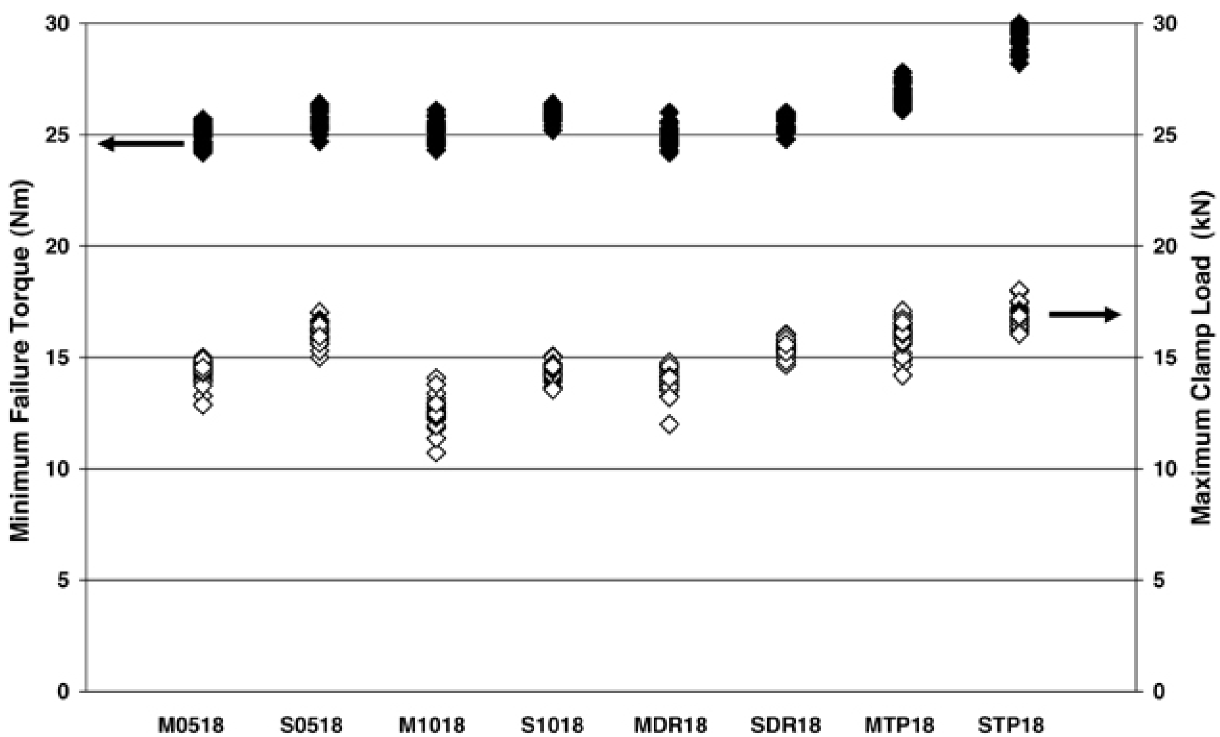

Figure 5. Minimum failure torque and maximum clamp load for cast aluminum alloy A380 test specimens.

Table 2. Summary of maximum clamp load and minimum failure torque for cast aluminum alloy 380 test specimens

Test combination	Maximum clamp load (kN)	Minimum failure torque (Nm)
M1018	12.6	25.1
M0518	14.3	25.1
MDR18	14.0	24.9
MTP18	16.0	27.0
S1018	14.2	25.9
S0518	16.1	25.6
SDR18	15.4	25.3
STP18	16.9	29.6
Nominal standard deviation	<0.5	<0.5

S-coating showing about 1 Nm higher than the M-coating. The tapped holes with machine fasteners showed slightly higher minimum failure torques relative to net-shape holes, and again, the S-coating was higher (29.7 Nm) than the M-coating (27.0 Nm). For maximum clamp load, hole geometry had a consistent effect with the 1.0° draft angle having the lowest clamp load, followed by the drilled holes, and the 0.5° draft angle having the highest clamp load. As with minimum failure torque, the S-coating was consistently higher than the M-coating. The standard deviations for all these measurements were minimal at less than 2–3% of the measured value.

Metallographic Evaluation

Representative fastener test specimens were selected for metallographic evaluation to characterize thread integrity relative to cast specimens with tapped holes and standard machine fasteners. Test specimens that failed by breaking of the fastener were sectioned axially, then mounted and polished for metallographic inspection. Figure 6 shows an optical micrograph of a standard machine fastener in a tapped as-cast aluminum nut specimen. The tapped threads are very clean and consistent along the axial length of the nut specimen and show no signs of significant cracking. Figure 7 is an optical micrograph of a TFF in a cast aluminum nut specimen with 0.5° draft angle. As expected, the threads formed using TFFs are not as clean when compared to a tapped hole with some minor cracking observed in the threads formed by installation of the fastener in the top end of the hole. However, no debris was created during thread-forming, and the clamp loads were acceptable for a M6 fastener. The light regions in the center of the fastener in Figure 7 are surface oxidation of the fastener alloy.

Future Work

The concept feasibility portion of this program was successfully completed in 2003. The results from this effort showed that clamp loads comparable to conventionally drilled holes and tapped fasteners could be achieved with TFFs in net-shaped holes. In addition, a broad-based team of participants was formed, including the automotive original equipment manufacturers (OEMs), fastener suppliers, assembly equipment suppliers, and manufacturers of cast components.

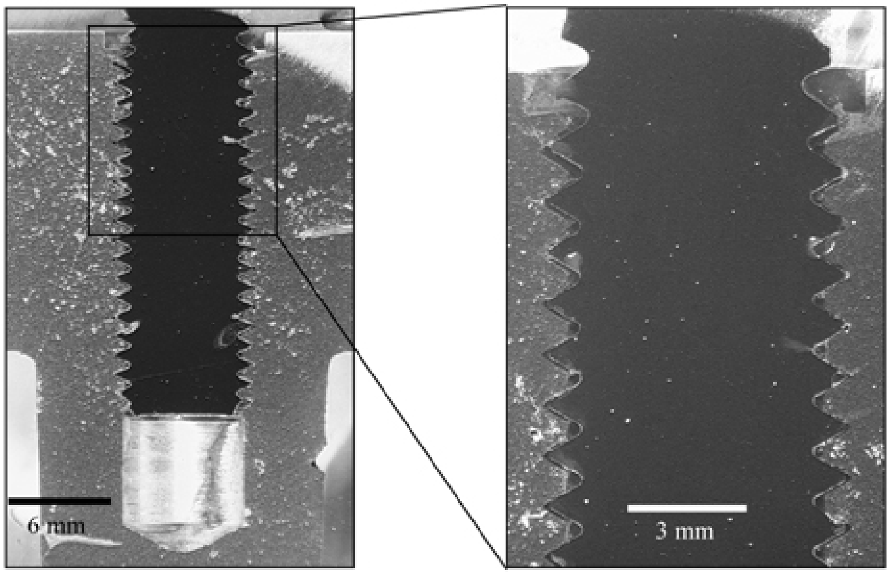

Figure 6. Optical microscopy of a cross section from an M6 standard machine fastener run into an as-cast aluminum nut specimen.

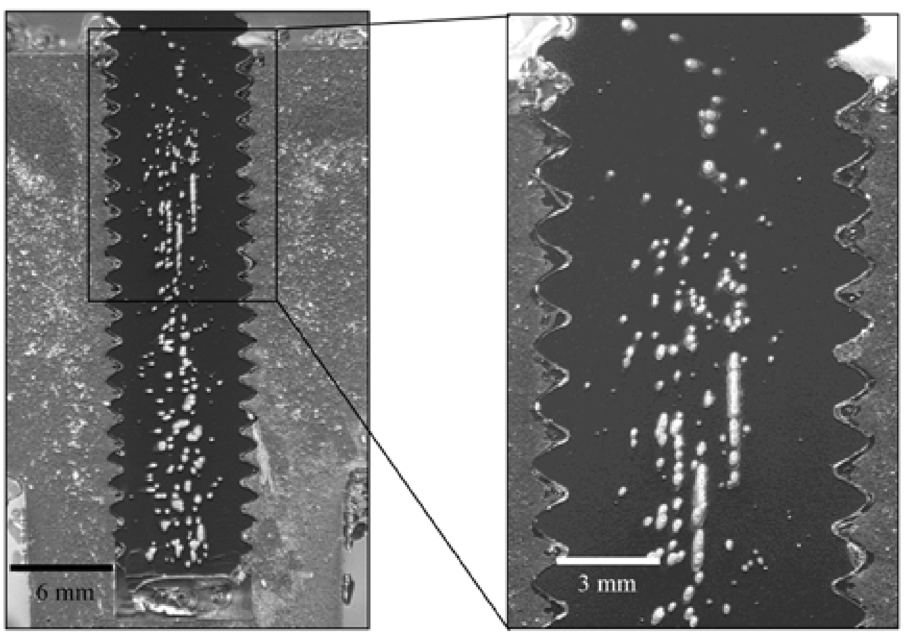

Figure 7. Optical microscopy of a cross section from an M6 TFF run into an as-cast aluminum nut specimen.

However, the application of TFFs in net-shaped holes of lightweight materials is not fully understood. Research and technical development are required to address issues associated with the casting process, thread-forming performance, joint integrity, assembly capability, and the impact to service. The objectives for the proposed technical feasibility portion of this program are as follows:

(1) Startup and Design Phase consists of developing the proof-of-concept experimental design and determining statistical

dimensional variable ranges for a series of die-cast test plates containing net-cast test holes for assembly of the TFFs. Statistical variability parameters will be verified by comparison to measurements taken in the field from production dies and tooling. Initial results from the concept feasibility parametric study will be validated with design and manufacturing engineering input prior to issuing design release for casting and assembly tooling.

(2) Build and Launch Phase will (1) design tooling and cast multiple die-cast test plates containing representative, statistically valid, dimensional variables; (2) install a production-representative automated nut runner system with required instrumentation; and (3) assemble a statistically valid number of TFFs into the multiple die-cast test plates.

(3) Run, Analyze, and Report Phase will characterize the assembly process, joint performance, and variability of fastener assembly parameters as a function of net-cast hole variables. These data will be compared to conventionally drilled and tapped holes. Results will be analyzed and reported along with a recommended assembly torque strategy for net-cast hole TFFs.